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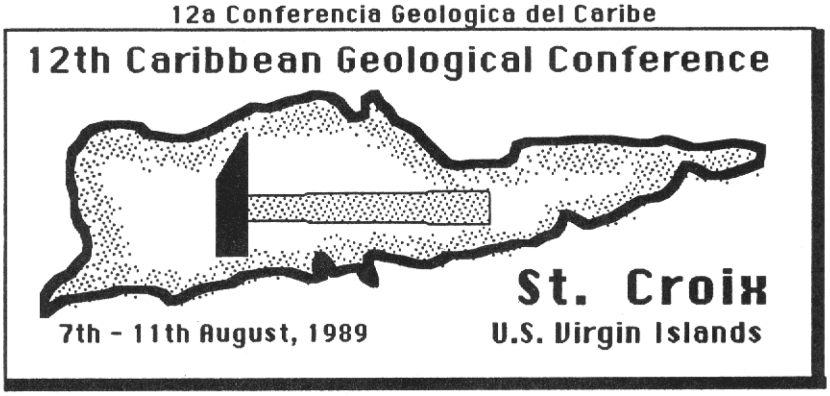

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A KINEMATIC HISTORY FOR EASTERN MARGARITA ISLAND, VENEZUELA

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ABSTRACT

Amphibolites, schists, and minor marble, together with serpentinized ultramafics and leucocratic igneous rocks, make up the metamorphic nucleus of Margarita Island. Knockers of eclogite found within the amphibolites and schists tie the island to similar rocks along the southern Caribbean coast characterized by the occurrence of high pressure metamorphic assemblages. This metamorphic belt is one of several exposed in the Caribbean Mountain System which extends from Tobago to Barquisimeto, parallel to the Caribbean-South American plate boundary.

Five generations of deformational structures have been identified on Margarita Island. The earliest deformation (D_{1a}) is rarely preserved. It occurs as the main foliation in the eclogite knockers and as a crenulated foliation within microlithons bounded by the foliation of the next deformation (D_{1b}). The D_{1b} phase of deformation is synchronous with epidote-amphibolite to greenschist facies metamorphism and formed the dominant metamorphic foliation which is axial planar to associated isoclinal folds. Following this stage of deformation, S-C and quartz c-axis fabrics developed which indicate SW-NE extensional deformation (D_{1c}). All D_1 phases may have occurred in the Cretaceous. In the Oligocene/Miocene, the D_2 phase of deformation folded the D_{1b} foliation into a northwest-vergent anticlinorium that plunges to the SW. The latest brittle deformation (D_3) also shows SW-NE extension.

All fold axes and extensions are aligned SW-NE. This is best explained by a continued component of dextral strike-slip deformation since the mid-Cretaceous. The data are consistent with recent plate kinematic models in which the rocks of Margarita formed far to the west along the Farallon-South American plate margin. The preserved deformations then reflect long-term dextral transport of these rocks along the southern boundary of a Farallon plate fragment as it rafted between the Americas to become the modern day Caribbean plate.

INTRODUCTION

The Caribbean-South American boundary is a complex region of plate interactions. The current boundary is diffuse, encompassing a width of several hundred kilometres and complicated by internal plate deformation (Case and others, 1984; Mann and Burke, 1984; Mascle and others, 1985). Adding to the confusion, most workers (for a review, see table 2 of Pindell and Barrett, in press) now believe that the modern Caribbean plate is a far-traveled oceanic plateau born in the Pacific Basin. Ocean crust, formed during the separation of the Americas, has been subducted beneath the more buoyant Caribbean crust and thus much of the evidence for the early history of the boundary has been destroyed.

Given the above limitations, it is unlikely that the rock record from any one area would contain the necessary and sufficient evidence to completely reveal the Caribbean tectonic history. Study of the current rocks in their current locations can, at best, provide only circumstantial evidence. With enough data from enough areas only a few of the proposed tectonic models will explain all observations. This study on the kinematic history of eastern Margarita Island provides one such line of evidence, that together with other studies elsewhere may help constrain the tectonic history of the southern Caribbean.

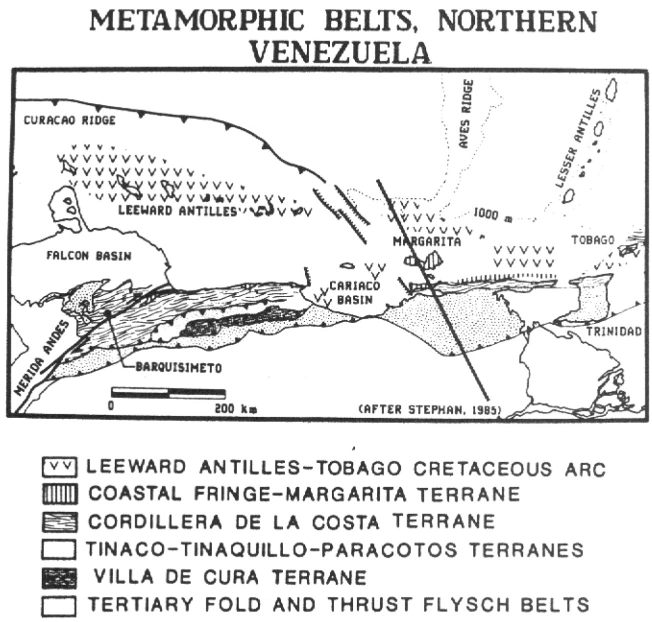

Figure 1. Simplified geologic map of the southern Caribbean and northern Venezuela, after Stephan (1985). The line of the schematic section in figure 2 is shown by the heavy line through Margarita.

REGIONAL GEOLOGY

Margarita Island is located in the southeastern Caribbean Sea (figure 1), where the metamorphic belts of northern South America intersect the arcuate trends of the Aves Ridge, the remains of a Late Cretaceous-Paleogene magmatic arc, and the Neogene Lesser Antilles volcanic arc (Case and others, 1984). The metamorphic belts of the Caribbean Mountain System are defined by lithologic and metamorphic affinities, but age constraints are poor. Some of the most recent descriptions of the metamorphic belts have been published by Case and others (1984), Stephan (1985) and Bellizzia (1986).

Preserved on the Leeward Antilles and Tobago and encountered in some wells drilled between the islands are portions of a Cretaceous magmatic arc. Along the coast, including parts of Margarita Island, is the narrow Coastal Fringe-Margarita nappe characterized by the occurrence of eclogite and blueschist facies rocks. The Cordillera de la Costa nappe is composed of a Paleozoic to Precambrian gneissic basement (Pimentel and others, 1985; Ostos, 1990) unconformably overlain by Mesozoic sedimentary and volcanic rocks (Case and others, 1984; Bellizzia, 1986), all metamorphosed in the Mesozoic to the greenschist facies. Grouped together for simplicity in figure 1 are the rocks labeled Tinaco-Tinaquillo-Paracotos terranes. These include Paleozoic metamorphic rocks of the El Tinaco basement complex (Case and others, 1984; Loubet and others, 1985); the alpine peridotites of the Tinaquillo ultramafic massif (Bellizzia, 1986); the Loma de Hierro

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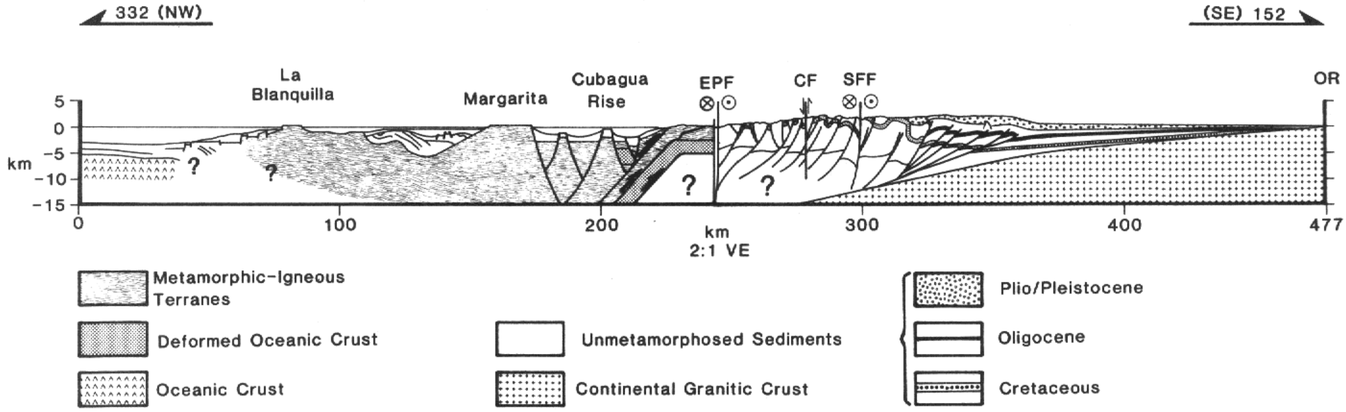


Figure 2. Regional schematic cross section from the Venezuelan Basin to the Orinoco River. The data for this section have been compiled from several published sources (Biju-Duval and others,1983; Ball and others,1971; Vierbuchen, 1984; Rossi and others, 1987; Young and others, 1956). Modifications in these earlier interpretations have been based on the current work and personal communications from F. Audemard (1990). Abbreviations used are EPF = El Pilar Fault, CF = Caripe Fault, SFF = San Francisco Fault, and OR = Orinoco River.

ophiolite; and the Maestrichtian to Early Tertiary Paracotos flysch (Case and others, 1984; González de Juana and others, 1980). The Villa de Cura terrane is composed of interbedded volcanics and sediments metamorphosed to the blueschist facies (Loubet and others, 1985). Stephan (1985) related this terrane with the Cretaceous arc exposed offshore while Ostos (1990) postulated that the Villa de Cura represents oceanic rocks metamorphosed in a Neocomian accreationary wedge.

In the south, unmetamorphosed fold and thrust belts formed as these metamorphic rocks were emplaced onto South America. The age of this deformation decreases from the Paleocene-Early Eocene in the west to the Miocene-Pliocene in the east, related to the progressive emplacement of these metamorphic belts (Pindell and others, 1988; Ross and Scotese, 1988). Figure 2 shows that these unmetamorphosed rocks south of Margarita Island form a south vergent thrust belt with a minimum shortening of 40 km (Rossi and others, 1987), while the actual shortening may be several times that amount (F. Audemard, oral communication, 1990).

The occurrence of ophiolites and rocks associated with magmatic arcs, together with the presence of blueschist and eclogite facies rocks all suggest that these metamorphic belts were formed along a convergent plate margin. Continued strike-slip motion between the Caribbean and South American plates has disrupted these belts, however, so that the regional trends portrayed in figure 1 are, in reality, fairly gross generalizations. This is emphasized in figure 2, where south of Margarita the metamorphic terranes have been disrupted by Neogene extensional faulting in the pull-apart basin at Cubagua and truncated by the El Pilar Fault.

GEOLOGY OF MARGARITA ISLAND

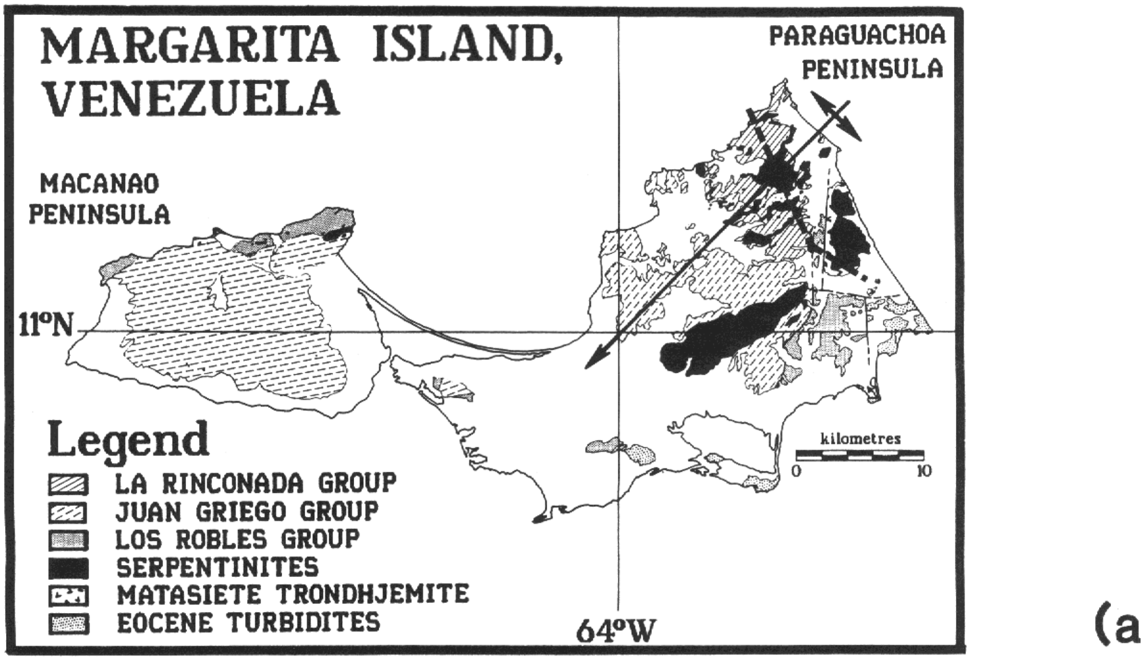
Figure 3a shows a simplified geologic map of Margarita Island, compiled from previous workers (Taylor, 1960b; González de Juana and Vignali, 1970; Muñoz, 1973; Maresch, 1975). The areal distribution of the units is displayed with a minimum of interpretation, since fundamentally different frameworks have been proposed for Margarita.

Earlier workers (Hess and Maxwell, 1949; Taylor, 1960; Maresch, 1971; 1975; Vignali, 1976; 1979) interpreted the metamorphic section in terms of a stratigraphic sequence. Maresch (1971, 1975) believed that the amphibolites of the La Rinconada Group were metamorphosed tholeiitic flows and intrusives formed during rifting (Beets and others, 1984). Amphibolites, quartzofeldspathic schists, graphitic schists, and marbles of the Juan Griego Group, and schists, phyllites, and marbles of the Los Robles Group then represent the metasedimentary cover. The decrease in metamorphic grade from amphibolites to phyllites and the arcuate distribution of the rock units permitted Taylor (1960) to infer an anticlinorium with the axis shown in figure 3a, cored by the La Rinconada Group and plunging to the SW. In this framework, the large serpentinized ultramafic massifs shown in figure 3a are interpreted as the remnants of a large complex infolded and metamorphosed with the other metamorphic rocks (Maresch, 1971; 1975) or thrust sheets capping the mountains of eastern Paraguachoa (Bellizzia and others, 1976; Chachati and Macsotay, 1985).

Chevalier and others (1985; 1988), Bellizzia (1986), and Chevalier (1987) proposed a radically different interpretation - that the serpentinites and the rocks of the La Rinconada and Los Robles Groups represent a metamorphosed ophiolite complex. Guillet and Cannat (1984) found microstructures in some of the rare unaltered olivines characteristic of asthenospheric plastic flow suggesting that the serpentinized ultramafic massifs represent oceanic mantle. The La Rinconada Group is then believed to be metamorphosed tholeiitic MORB crust with its metasedimentary cover represented by the Los Robles Group. This ophiolitic nappe of the Coastal Fringe-Margarita Belt was then emplaced onto the parautochthonous Juan Griego Group belonging to the Cordillera de la Costa Belt and representing a remnant of the old South American passive margin (Bellizzia, 1986).

Figure 3b contrasts these two disparate interpretations. The section by Maresch (1975) shows the steep contacts of rocks infolded within the core of the anticlinorium. The same section by Chevalier (1987) envisions the suite of meta-ophiolitic rocks disrupted by dominantly SE directed thrusts.

Within the La Rinconada and Juan Griego Groups occur lenses and boudins of eclogite. Several studies of these eclogites concluded that these rocks formed under peak metamorphic conditions of P=1.15-1.5 GPa and T=450-700°C (Maresch and Abraham, 1981; Chevalier, 1987). Retrograde trajectories produced partial re-equilibration through metamorphic conditions of P=700-800 MPa and T=400-520°C (Navarro, 1981) down to P<500 MPa and T=480-550°C (Maresch and Abraham, 1981). Chevalier (1987) agreed with Maresch and Abraham (1981) that the eclogite, epidote-amphibolite and greenschist facies metamorphic rocks found on Margarita Island formed in a single Late Cretaceous prograde-retrograde metamorphic cycle. However, other workers used the mineral chemical zonation and the observed reaction textures to infer two discrete metamorphic events (Blackburn and Navarro, 1977; Stephan and others,1980; Navarro, 1981; Talukdar and Loureiro, 1982; and Chevalier and others, 1985). They associated the first of these, a postulated Late Jurassic or Early Cretaceous obduction of oceanic crust onto the South American margin, with the eclogite facies metamorphism. Chevalier (1987) and Chevalier and others (1988), however, relate this obduction with high temperature (T>1000°C) deformation. All workers agree with a Late Cretaceous collision of an island arc with South



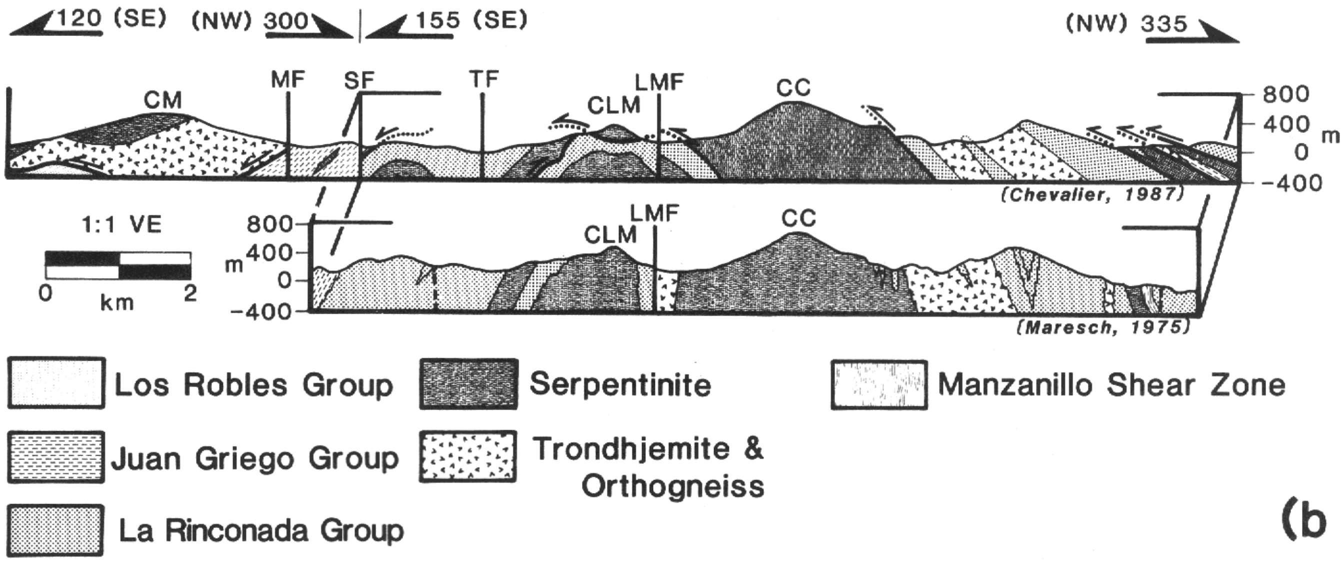


Figure 3a. Generalized geological map of Margarita Island, Venezuela compiled from published sources (Taylor, 1960b; González de Juana and Vignali, 1970; Muñoz, 1973; Maresch, 1975). The axis of the SW plunging anticlinorium inferred by Taylor (1960) is shown, as well as the line of section shown in figure 3b. The unusual shape of the island makes it convenient to refer to the western portion as Macanao and the eastern portion as Paraguachoa.

Figure 3b. Cross sections through Margarita Island from Maresch (1975) and Chevalier (1987). Maresch (1975), using a stratigraphic interpretation, inferred steep contacts within the core of the anticlinorium. Chevalier (1987) re-interpreted many of these contacts to be thrusts, emplacing meta-ophiolites represented by the serpentinites and the La Rinconada Group from the NW to the SE. CM=Cerro Matasiete, CLM=Cerro Los Micos, CC=Cerro Chico, MF=Matasiete Fault, SF=Salamanca Fault, TF=Tacarigua Fault, LMF=Los Micos Fault.

America, with the Coniacian-Campanian time range most often cited (Talukdar and Loureiro, 1982; Beets and others, 1984; Chevalier and others, 1985; 1988).

Leucocratic igneous rocks intruded and were metamorphosed with the La Rinconada and Juan Griego Groups. Most of these bodies are too small to be shown at the scale of figure 3a. However, in a fault bounded block along the eastern coast of the island, a large metatrondhjemite body is capped by serpentinite. Published trace-element analyses of the Matasiete Trondhjemite (Chachati and Macsotay, 1985; Ostos, 1990) plotted on the discrimination diagrams of Pearce and others (1984) indicate that these rocks were formed by subduction-related magmatism and are not oceanic plagiogranites formed along a mid-ocean ridge. Amphibole separates from this unit gave K/Ar ages of 72±5, 74±6 and 72±6 Ma (Olmeta, 1968; Santamaría and Schubert, 1974: recalculated using the Steiger and Jäger 1977 decay constants). However, other published K/Ar ages using various mineral separates from the La Rinconada Group range between 98 and 37 Ma (Loubet and others, 1985; Chevalier, 1987), suggesting a complex thermal history and partial argon loss (Burke, 1988).

Along the southern margin of Margarita Island, unmetamorphosed but folded turbidites are exposed. Hunter (1978) inferred that these rocks were deposited between the Lower Eocene and the uppermost Middle Eocene based on the microfaunal assemblages, although reworking has introduced conglomeratic or brecciated fragments with Cretaceous and Paleocene fauna (Muñoz and Furrer, 1976; Hunter, 1978; Muñoz, 1983). The folding of these rocks may have occurred in Oligocene/Miocene time. Capping these rocks are relatively undeformed units of Late Miocene age and younger (not shown in figure 3a).

Based on the orientation of the Miocene folds, the island can be divided into 5 regional structural domains. Shown on figure 4, these domains are 1) Macanao Peninsula, 2) the lowland of SW Paraguachoa Peninsula, 3) the La Rinconada, Juan Griego and Los Robles Groups of eastern Paraguachoa, 4) the fault-bounded Matasiete Trondhjemite and 5) the fault-bounded Eocene turbidites on the far eastern corner of the island (Pampatar Formation).

KINEMATIC ANALYSIS

The analysis presented here is confined to the La Rinconada, Juan Griego, and Los Robles Groups of eastern Paraguachoa. Hence, the data all come from a single structural domain - the SW plunging anticlinorium originally described by Taylor (1960) and shown as structural domain 3 in figure 4. The various phases of deformation will be described in order of oldest to youngest, with the corresponding lower-hemisphere, equal-area stereonets shown in figure 5.

The D_{1a} deformation is related to the eclogite facies metamorphism. The data shown in figure 5a are the foliations in the eclogites and the rare planar fabrics preserved in microlithons between the main D_{1b} foliation in the schists. Most of the evidence for this deformation has been destroyed, explaining the sparseness of the data set.

The dominant foliation of the metamorphic rocks on Margarita Island is related to the D_{1b} deformation associated with epidote-amphibolite to greenschist facies metamorphism. A plot of this foliation in figure 5b shows that this fabric has been folded into a great circle distribution with a SW trending fold axis which is the regional D_2 fold axis. Comparison of the D_{1a} and the D_{1b} foliation fabrics shows that they have similar distributions. Talukdar and Loureiro (1982) found comparable deformations in the rocks of the Coastal Fringe-Margarita terrane NW of Caracas; isoclinal folds that developed during the greenschist/epidote-amphibolite facies metamorphism are coaxial and coplanar to the earlier folds formed during blueschist/eclogite facies metamorphism.

The folds on Margarita associated with these two phases of deformation could not be distinguished in the field unless a refolded fold was found. As a result, all fold axes defined by folded compositional layering are plotted together in figure 5c. The most obvious feature of this stereonet is the concentration of the fold axes aligned SW-NE and sub-parallel to the regional D_2 fold axis. Evidence from other domains on Margarita and from similar rocks on the Araya Peninsula (Avé Lallemant, this volume) shows that these fold axes are parallel to the finite strain X (maximum extension) axis. Since these axes are near parallel to the later D_2 fold axis, the D_2 deformation did not significantly rotate these data.

Small scale shears and quartz c-axis fabrics can be used to infer the kinematics of deformation. S-C tectonites form when a penetrative schistosity (S-surface) is offset by shear planes ("cisaillement" or C-surfaces). The angular relationship between the two defines the sense of movement in sheared rocks (Berthé and others, 1979; Simpson and Schmid, 1983; Lister and Snoke, 1984). Asymmetries in quartz c-axis fabrics have also been related to the kinematics (Lister and Williams, 1979; Simpson and Schmid, 1983).

Field measurements of small scale conjugate shear sets and quartz c-axis fabrics from the schists of the Juan Griego and Los Robles Groups define the D_{1c} extensional phase of deformation shown in figures 5d,e,f. The poles to the shear planes are plotted in figure 5d to show that these deformational structures were also

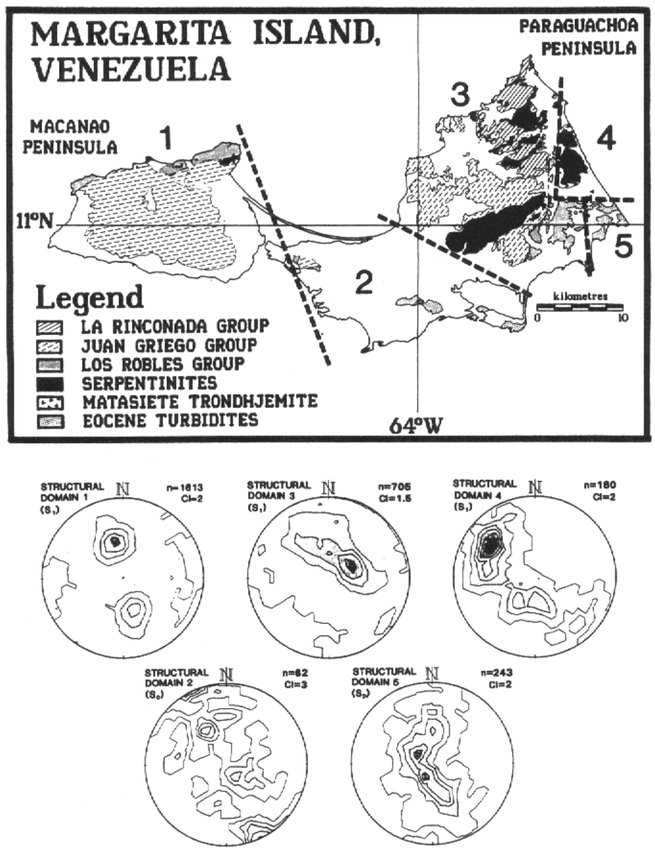


Figure 4. Based on the orientation of the D_2 folding, the island can be divided into the 5 structural domains shown on the smaller version of figure 3a. Boundaries between domains 3, 4 & 5 are known faults; boundaries between domains 1, 2 & 3 are inferred faults. The trends of the La Rinconada and Juan Griego patterns are parallel to the observed D_2 structural trends. The stereonets below the map display the regional structural orientations. These are lower-hemisphere, equal-area projections. CI is the contour interval as % per 1% area and n is the number of measurements used to construct the diagram. The data from structural domains 1 and 2 come from published sources (Hess and Maxwell, 1949; Kugler, 1957; Taylor, 1960b; Rengel, 1961; González de Juan and Vignali, 1969; 1970; Muñoz, 1973), while the measurements from domains 3, 4 and 5 come from this study. In the 2 domains dominated by Eocene outcrop (2 and 5), bedding (S_0) defines the regional structure while in the other domains (1, 3, and 4), foliation (S_1) was used to define the structure.

Figure 5. The structural data from the La Rinconada, Juan Griego and Los Robles Goups of eastern Paraguachoa (domain 3 on figure 4). All stereonets are lower-hemisphere, equal-area projections. CI is the contour interval as % per 1% area and n is the number of data points used to generate the diagram. The 1st row shows structures from the eclogite facies D_{1a} and the epidote-amphibolite facies D_{1b} deformations. The 2nd row shows the greenschist facies D_{1c} extensional structures. The 3rd row illustrates the D_2 features and the 4th row displays the Neogene brittle deformation. In figures 5e, f, and k, the great circles are shear planes and the arrows indicate the direction of motion of the hanging wall across the footwall. Figure 5l shows the orientation of Riedel (R) and conjugate Riedel (R') shears.

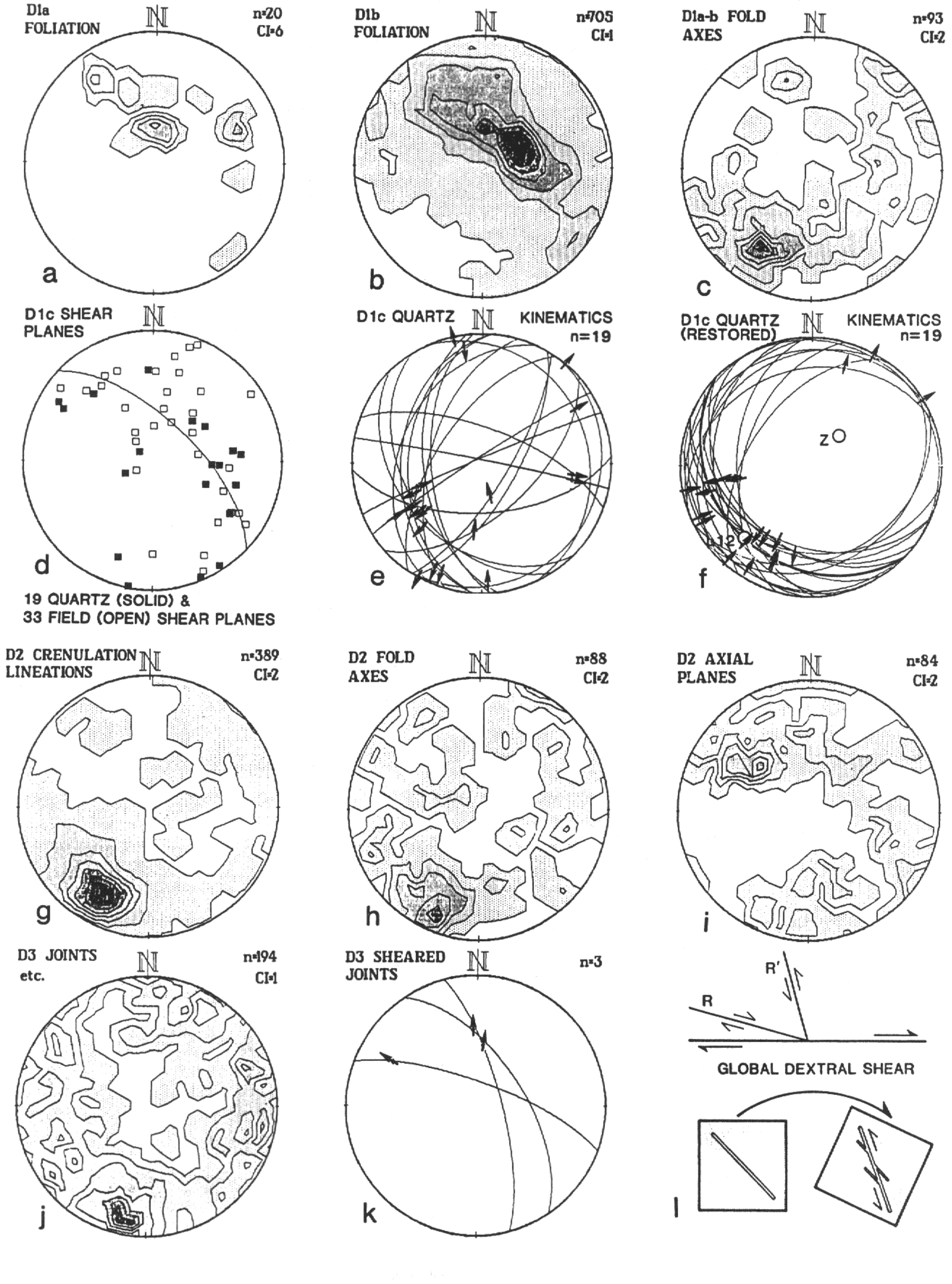


Figure 5. The structural data from the La Rinconada, Juan Griego and Los Robles Groups of eastern Paraguachoa (complete caption on previous page).

folded. The best fit great circle girdle distribution of the foliations shown in figure 5b is plotted on figure 5d to illustrate the similar patterns created by the later D_2 folding. The low angular relationship between foliation and extensional shears make inferences of the slip direction in the field data questionable. Quartz c-axis data therefore form a more reliable data set to define the kinematics, and the results are presented in figures 5e,f. The inferred shear planes are plotted as great circles and the arrows indicate the direction of motion of the hanging wall across the footwall. Of the 20 quartz c-axis fabrics measured, 19 have asymmetric fabrics for which a sense of shear can be determined. Each fabric was generated using 3 mutually perpendicular thin sections with a minimum of 293 c-axes per fabric. Unrestored, there is a wide scatter in the shear planes due to the later D_2 folding but the slip directions are generally SW-NE (figure 5e). With the effects of the D_2 folding removed, the extensional fabric is clearly defined, showing SW-NE extension (figure 5f). The mesoscopic pole to the foliation plane (Z) and crenulation lineation (L12) are shown in their restored positions on figure 5f. The quartz c-axis fabrics demonstrated that the mesoscopic D_2 crenulation lineation could be used to approximate the D_{1c} finite strain X axis.

The structural data for the D_2 folding are shown in figures 5g,h,i. Crenulation lineations and mesoscopic fold axes are parallel, plunging to the SW (figures 5g,h). These folds were observed to be generally NW-vergent, and this is substantiated by the stereonet of the axial planes of the mesoscopic folds measured in the field (figure 5i).

The D_2 deformation folds the Eocene turbidites but not the Mio-Pliocene Cubagua Formation, apparently bracketing the age of folding between the late Middle Eocene and the Late Miocene. However, even these wide age constraints are not accepted by all workers. Vignali (1976, 1979) suggested that the D_2 folding began in the Late Paleocene with maximum activity in the late Middle Eocene and finally ending in the Late Oligocene to Early Miocene. Taylor (1960) and Muñoz (1983) thought that the Eocene turbidites were deposited in a tectonically active basin, so syndepositional folding of these units is not unreasonable. Seismic data from the continental slope north of Margarita Island, correlated with well information, suggests that folding continued through the Middle Miocene (Biju-Duval and others, 1983). The one absolute age date associated with this deformation is the 33±2 Ma feldspar K/Ar age of a pegmatite from Macanao (Santamaría and Schubert, 1974: recalculated with the decay constants of Steiger and Jäger, 1977). Vignali (1976, 1979) found these pegmatites to be influenced by the D_2 folding, but interpreted the date to be the younger limit of the D_2 deformation because of the low blocking temperature of feldspar to argon loss (Harrison and McDougall, 1982; Harrison and others, 1989).

It is tempting to describe the NW-vergent D_2 folding on Margarita Island as the hinterland deformation associated with the Oligocene-Miocene subsidence and the Miocene SE-directed thrusting in the foreland Eastern Venezuelan Basin to the south (González de Juana and Rodriguez, 1951; Cebull, 1970; Vierbuchen, 1984; Rossi and others, 1987; Isea, 1987). However, care must be taken in making correlations across the Caribbean-South American plate boundary. Accepting the 20 $mm \cdot a^{-1}$ relative motion of the Caribbean with respect to South America (Ross and Scotese, 1988; Pindell and others, 1988) places Margarita Island too far west to be directly related with the deformation in the Eastern Venezuelan Basin (figure 6). Curiously, the paleogeographic reconstructions shown in figure 6 place the late Eocene-Oligocene pullapart preserved in the Falcon Basin (Muessig, 1984) and the Quaternary opening of the Tuy-Cariaco Basin (Schubert, 1982) in the immediate wake of Margarita Island.

Clearly, the age of the D_2 folding is not well constrained. Most of the interpretations, however, overlap in the Oligocene through middle Miocene time range.

Figures 5j,k,l show the brittle structures measured in structural domain 3. Figure 5j plots all joints, veins and extensional fractures that post date the D_2 folding. These show SW-NE extension. Some

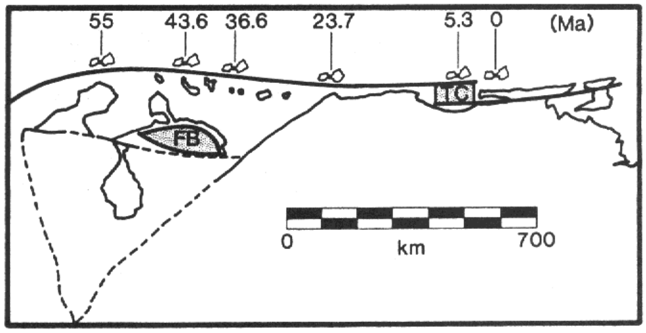


Figure 6. The paleogeographic location of Margarita Island is shown with respect to South America. Dewey and Pindell's (1985) restoration of the Maracaibo Block has been used to estimate the pre-Andean shape of South America. The basins shown are the Falcon Basin (FB) and the Tuy-Cariaco Basin (TC).

joints are sheared, fringed by newer en-echelon extension fractures. Only three were observed in this structural domain (figure 5k) but the data are supported by similar joints and dextral EW faults seen in the other structural domains. In figure 5k, the sheared joints are plotted as great circles and the arrows indicate the direction of motion of the hanging wall across the footwall. These sinistrally sheared joints can form in a global dextral shear environment. Tchalenko (1970) showed that secondary faults associated with a master strike-slip fault often develop into a conjugate set of Riedel shears, one set synthetic (R) to the main fault and one set antithetic (R'). Alternatively, the sheared joints could develop as rotated tension cracks (figure 5l).

The possibility of tectonic block rotations raised in figure 5l for the origin of sheared joints on Margarita Island has a profound affect on the interpretation of the kinematic data, particularly since paleomagnetic data have documented about 90° clockwise rotations in other rocks along the southern Caribbean margin (Skerlec and Hargraves, 1980). Hargraves and Skerlec (1980) measured 35 samples, mostly basic dikes, from 7 sites on Margarita Island. However, pervasive alteration and the resultant weak paleomagnetic signal produce data that are inconclusive (Hargraves and Skerlec, 1980).

A POSSIBLE PLATE TECTONIC MODEL

Figures 5c,e,f,g,h,j show that fold axes and extension directions on Margarita Island always had the same trend. Any permissible tectonic model will have to account for this observation. The simplest explanation extrapolates the present back into the past to conclude that these structures resulted from a continuous component of dextral motion. Based on this data and the data from Araya Peninsula, we propose that the rocks on Margarita Island represent an accretionary complex formed by oblique subduction between the Farallon Plate and South America. As the Farallon Plate entered the gap between the Americas, the increasing obliquity of the subduction zone explains the sequence of synmetamorphic deformations found in this study.

Figure 7a illustrates the model proposed by Avé Lallemant and Guth (in press) to explain how an increasing angle of obliquity can produce the progression of metamorphic grade and structures seen in the synmetamorphic deformation on Margarita. The accretionary wedge can only move with the tangential component of the underthrusting slab (V_T). As the angle of obliquity increases, V_T increases while the convergent motion normal to the plate boundary decreases. The resultant change in velocity of a constant volume accretionary wedge forces plate boundary parallel extension, thinning of the accretionary wedge and uplift of the base of the wedge. When the obliquity is 90°, subduction is totally eliminated and the plate boundary becomes a transform fault. Hence, as hinted by the labeling of the deformations and as shown on figures 7a and b, the eclogite facies D_{1a}, the epidote-amphibolite facies D_{1b}, and

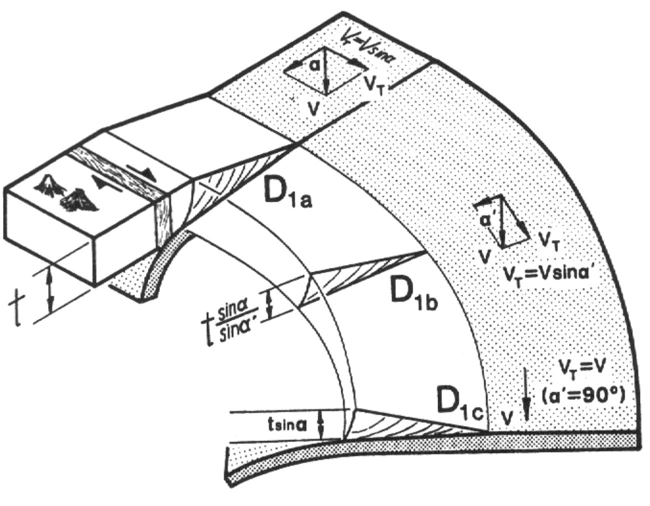


Figure 7a. The inferred deformations within an oblique subduction zone. The shaded plate is the subducting oceanic slab. The total relative plate motion is directed downward, resolved into normal and tangential components. The mechanics of this model is discussed in the text.

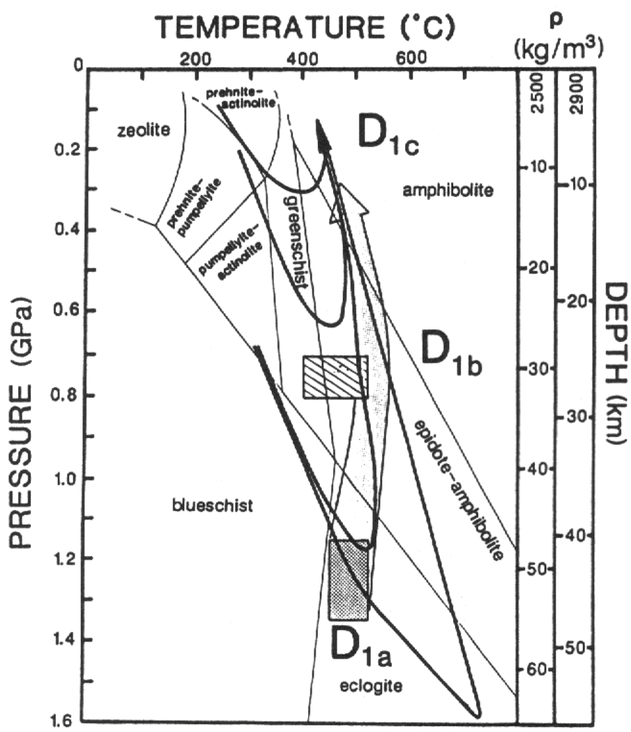


Figure 7b. Pressure-temperature estimates for the Late Cretaceous metamorphism are plotted on the schematic petrogenetic grid of Ernst (1988). The P-T trajectory inferred by Maresch and Abraham (1981) is shown with the stipple patterns, while 4 P-T trajectories from figure 108 of Chevalier (1987) are shown with the heavy lines. The field shown with the diagonal pattern is the P-T estimate for the retrograde metamorphism of Navarro (1981). Depth estimates have been computed for densities of 2500 and 2900 kg/m^3 to model depths in an accretionary prism and island arc, respectively. These values come from Speed and others (1984).

the extensional greenschist facies D_{1c} deformations represent a continuous process and not discrete deformational events.

Figure 7b gives some vertical scale to figure 7a by plotting the metamorphic conditions inferred by earlier workers and the associated deformations found in this study. The peak metamorphic pressures inferred by Chevalier (1987) range from 300 MPa to 1.5 GPa, but the maximum pressure gradient occurs between the middle two curves which show a change in pressure of 600 MPa in samples about 8 km apart. Although Chevalier (1987) proposed a complex tectonic history to explain the geometry, we suggest that the extensional D_{1c} deformation provides a simple mechanism to remove the inferred 16 km of missing section between the two sample sites (assuming a density of 2500 kg·m^{-3})

The later non-metamorphic D_2 folding and D_3 brittle deformations are associated with the dextral Caribbean/South American plate boundary zone. The sequence of deposition and deformation are likely related to restraining and releasing perturbations along the strike-slip boundary.

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